

# Multispectral Imagery Research and Applications

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# NASA SPoRT Overview

SPoRT was established in 2002 with a focus on transitioning unique NASA satellite observations and research capabilities to end users to improve short-term operational weather forecasting and decision support.

The SPoRT paradigm (right) has been used to successfully transition over 40 satellite datasets and research capabilities to operational users for nearly 20 years

## Research Areas:

Tropical Meteorology

Atmospheric Remote Sensing

Lightning/ Convection

Air Quality / Human Health

Land Surface Remote Sensing

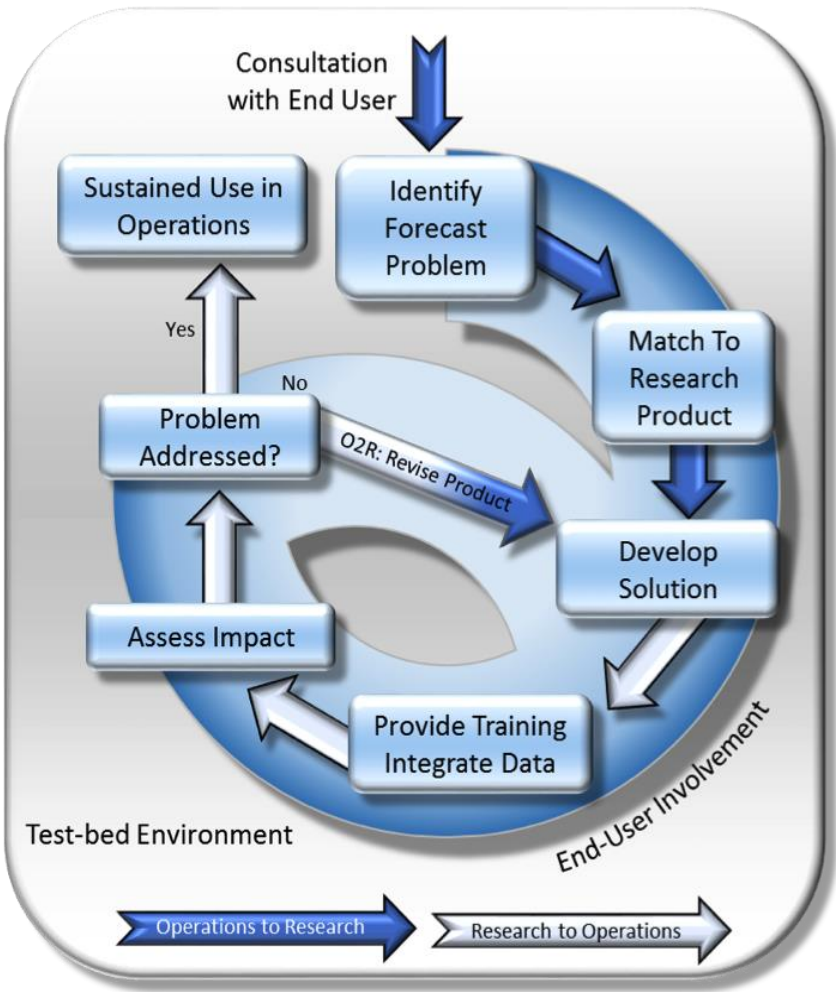
## Stakeholder Transition Activities:

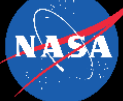
End-User Training

Product Assessments

Data Production

## Current Partners





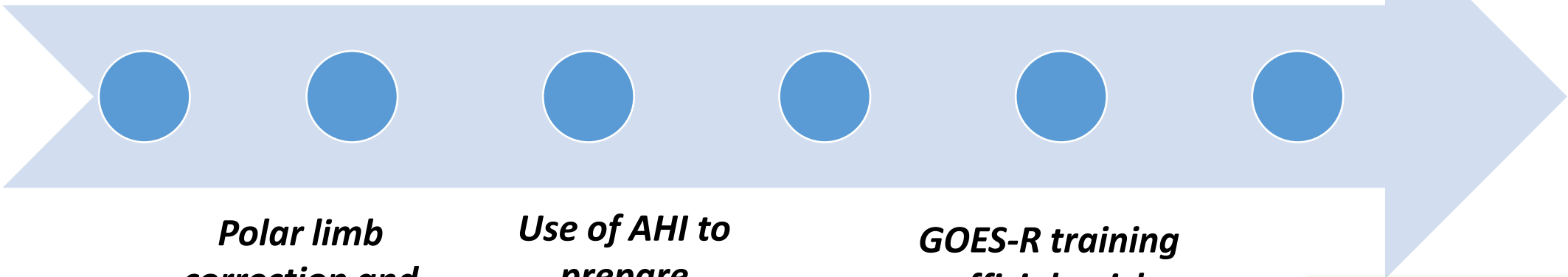
# Early SPoRT RGB Research & Applications



*Early application  
& training of  
MODIS/VIIRS  
RGBs to prepare  
for GOES-R*

*Adaption of limb  
correction &  
intercalibration  
to GEO*

*Early assessment  
of GOES-16 Dust,  
NtMicro, Day  
Cloud Phase in  
operations*



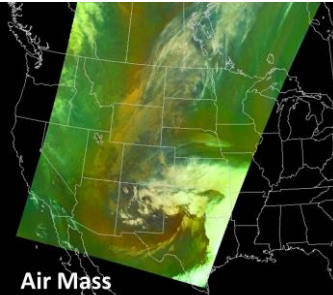
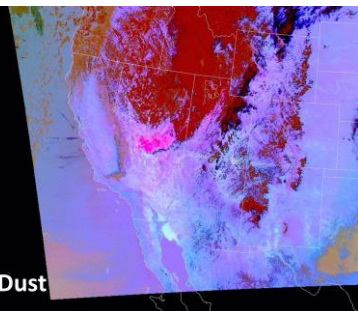
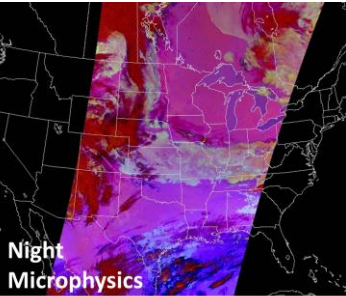
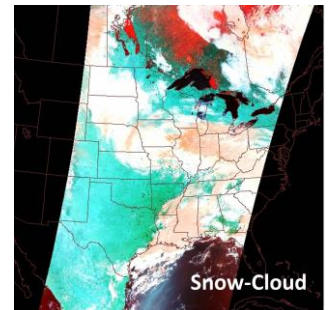
*Polar limb  
correction and  
intercalibration*

*Use of AHI to  
prepare  
forecasters for  
GOES-R*

*GOES-R training  
official quick  
guides & modules*

**ML/AI to  
improve  
detection and  
interpretation**


**Refining and  
using the GEO  
constellation**





- 2017-2018 Official GOES-R Training
- Quick Briefs and Quick Guides

- ### Nighttime Microphysics RGB for Air Quality

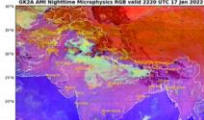


www.cmc.ucar.edu

  - ☒ Background and Origins
  - ☒ Real Component
  - ☒ Green Component
  - ☒ Blue Component
  - ☒ Final Product
  - ☒ Warm to Cold Season
  - ☐ Applications
  - ☒ Low Cloud vs Fog
  - ☒ Improved AQ Forecasts for the Next Day
  - ☐ More
  - ☒ Summary of Nighttime RGB

## Fog as Proxy to Stable Layer for AQ Issues

The NMicro RGB allows a user to identify low cloud and fog areas as a proxy to where stable layers exist which might lead to trapped pollutants the following day until the boundary layer mixes. Examine the regional view for another event from January 17–18, 2022, and note many areas of fog and low cloud development, particularly in cloud-free areas or where high clouds exit or dissipate.



- International Quick Guides

**SPORT**

**Example RGB Night-Time Microphysics Imagery from VIIRS - 2013, November 15**

Fog and low cloud pattern is similar due to use of 10.8-3.9 spectral difference, but the optical thickness and thermal information provide even greater contrast between the fog and low clouds compared to the standard spectral difference alone.


The dull appearance and lower contribution of red (optical depth) compared to clouds to the north indicate fog vs. low level clouds. The 3.8-3.9um imagery does not distinguish fog from low clouds.

**Example RGB Night-Time Microphysics Imagery from VIIRS - 2013, October 20**

This image is an example. The RGB shows fog in a dull equie to gray coloration affecting the coast of Canada to Washington State.

Red color indicates thick clouds. Oranges and yellows are mid-level clouds. Low clouds appear in shades of light blue or light green, depending on warm or cold temperature contribution.



Low, cold cloud



**GEMS**  
Global Earth and Meteorological Science

# Nighttime Microphysics RGB

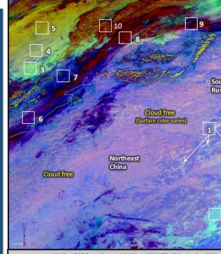
## Quick Guide

### RGB Interpretation

- 1 Fog (dark blue to grey)
- 2 Very low, warm cloud (cool)
- 3 Low, cool, cloud (light green)
- 4 Mid, warm, cloud (light green)
- 5 Mid, thick, water/ice cloud (thin, red)
- 6 Mid, thick, ice cloud (orange)
- 7 Mid/high, thin ice cloud (dark blue)
- 8 High, thick cloud (dark red)
- 9 High, thin cloud (near black)
- 10 High, thick, very cold (red/purple, near black)


Colors shown may vary slightly, depending on the color calibration used.



Weather Channel from Meteosat-8 and AT of ERSST V2, 15 November 2013


### Comparison to Other Products

The "15.5  $\mu$ m" or "Special Difference" RGB has traditionally been used to maximize low-level cloud differences. The color enhancement shows fog, low clouds, and even some mid-level water clouds colored in yellow while the Meteosat RGB isolates separate these features as additional cloud features.





### Resources

- [UKAR/COMET](#)
- [Multispectral Satellite Applications: RGB Products](#)
- [NASA/JPST](#)
- [Aviation Forecasting RGB Products](#)
- [EUMETSAT](#)
- [RGB Interpretation Guide](#)




[illegible]





# Nighttime Microphysics RGB

## Quick Guide




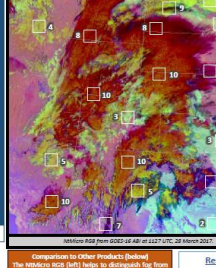
### RGB Interpretation

1	(dark) (aque to gray)
2	very low, warm cloud (brown)
3	low, cool cloud (light green)
4	Mid water cloud (light gray)
5	low, thick, warm/ ice cloud (pink)
6	High, thin, ice cloud (pink)
7	High, very thin, ice cloud (purple)
8	High, thick cloud (dark red)
9	High, thin, cold cloud (red)
10	High, thick, very cold cloud (red/pink, magenta)

Note: Colors may vary slightly, depending on the instrument used.

### RGB Color Guide






IMDPRG RGB PRM-0002 18 APR at 1827 UTC 22 APR 2002

#### Comparison to Other Products Below


The **Nimbus RGB (NPR)** helps to distinguish fog from clouds and “false alarm” features (see in the lower right) or **00.3-3.0** per channel difference (right). Recall the **0.5-3.0** per chn. in this in the past.

#### ES&RTS

**ES&RT/GOVNET**  
**Multisensor/GOVNET**  
**Particulate/NOI Product**  
**Estimated**  
**Nimbus Microphysics RGB Module**  
**ES&RT/NET**  
**RGB Interpretation Guide**




*Hypervisible not available when viewing material in RGB Text*



# SEVIRI Night Microphysics RGB

## Quick Guide



**Primary and secondary clouds** are the most visible in this RGB type and color scale. **Thin cirrus** and **thin altostratus** are not visible. **Partial cloud coverage** is a sign of a **low-level cloud deck**.

**Thin cirrus** and **thin altostratus** are the most visible in this RGB type and color scale. **Thin cirrus** and **thin altostratus** are the most visible in this RGB type and color scale. **Thin cirrus** and **thin altostratus** are the most visible in this RGB type and color scale.

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### Background

The table below describes the primary and secondary clouds in this RGB type and color scale. The table below describes the primary and secondary clouds in this RGB type and color scale. The table below describes the primary and secondary clouds in this RGB type and color scale.

Color	Clouds identified (identified)	Primary reason for identification	Secondary reason for identification	Lowest cloud top height (km)	Lowest cloud base height (km)
Red	SEVIRI-02-02-01	Cloud optical thickness	Thin cirrus	Thin cirrus	Thin cirrus
Green	SEVIRI-02-02-02	Cloud phase	Thin cirrus	Thin cirrus	Thin cirrus
Blue	SEVIRI-02-02-03	Cloud top temperature	Thin cirrus	Thin cirrus	Thin cirrus

**Notes:** SEVIRI-02-02-01: cloud optical thickness of the cloud top; SEVIRI-02-02-02: cloud phase of the cloud top; SEVIRI-02-02-03: cloud top temperature of the cloud top.

### Details

**Thin cirrus** and **thin altostratus** are the most visible in this RGB type and color scale. **Thin cirrus** and **thin altostratus** are the most visible in this RGB type and color scale. **Thin cirrus** and **thin altostratus** are the most visible in this RGB type and color scale.

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### Limitations

**Thin cirrus** and **thin altostratus** are the most visible in this RGB type and color scale. **Thin cirrus** and **thin altostratus** are the most visible in this RGB type and color scale. **Thin cirrus** and **thin altostratus** are the most visible in this RGB type and color scale.

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Metereological Satellite Center (MSC) of JMA

Ver. 1.0.0

# Himawari Night Microphysics RGB Quick Guide

**Main applications:** Cloud analysis, especially in detection of fog/low clouds at nighttime

**Benefits:**

- High contrast between water clouds (blue) and clouds and cloud-free surfaces
- Efficiency for nighttime cloud analysis
- Identification of the hotspots

**Limitations:**

- Available during nighttime only (all clouds appear magenta during the daytime)
- Difficulty of discriminating between fog and low clouds from Night Microphysics RGB data alone
- Effect on cloud color (especially fog) due to clouds and surfaces from thermal conditions (i.e., latitudinal, seasonal and diurnal variations)

**Fog/low-level clouds around the East China Sea and the Yellow Sea (21:00 UTC, 27 March 2018)**

**A** □ : fog/low-level clouds  
**B** ■ : land and ocean (cloud-free);  
**C** ■ : thin cirrus clouds  
**D** ■ : thick mid-level clouds

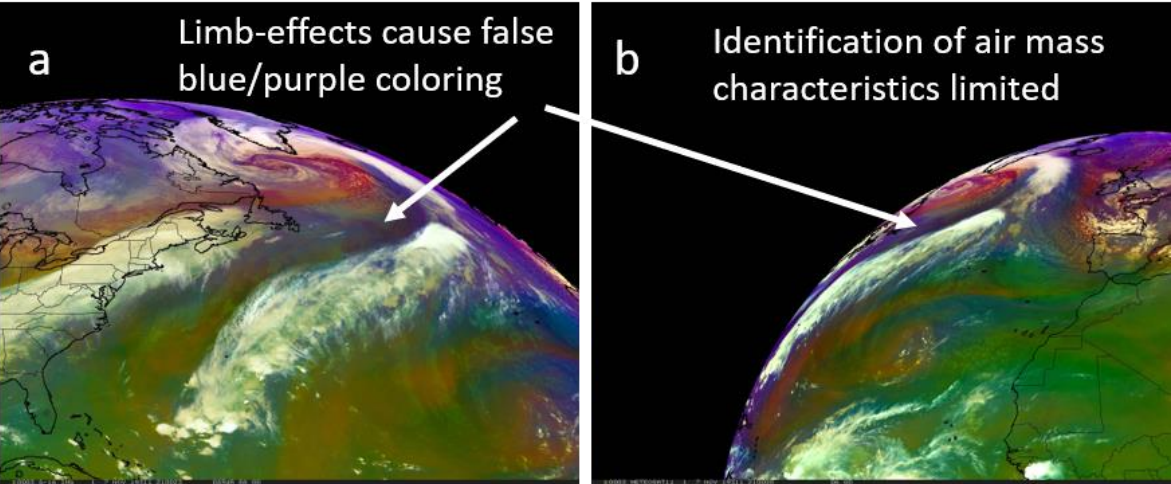
**Fog/low-level cloud around the East China Sea, Japan to South Korea, 18 November 2013**

**A** □ : fog/low-level cloud  
**B** ■ : high-mid-level cloud  
**C** ■ : thin cirrus cloud

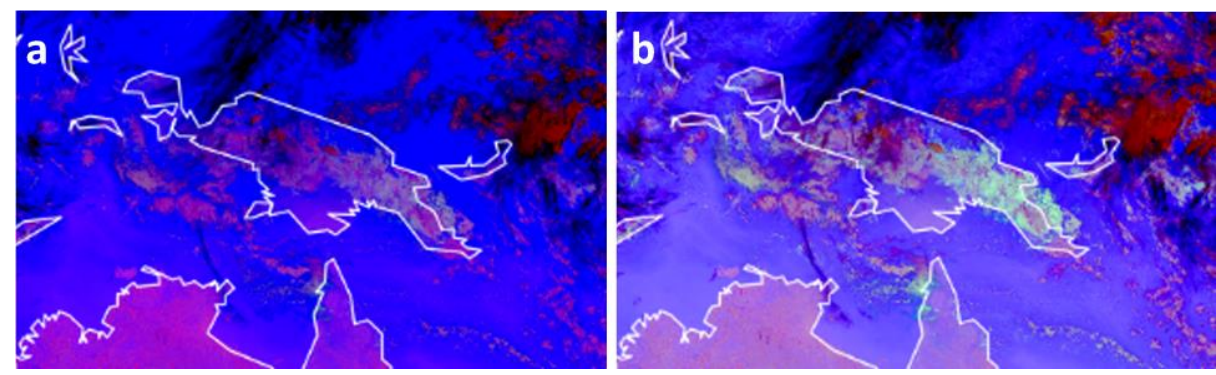
2017-11-18 00:00 JST 1.0 km



The use of RGB imagery derived from infrared and water vapor bands on a global basis is not without limitations due to the impact of limb-effects at high viewing angles and subtle spectral channel differences between satellites



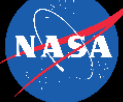
7 Nov. 2019 2100 UTC Air Mass RGB (a) GOES-16, (b) SEVIRI,



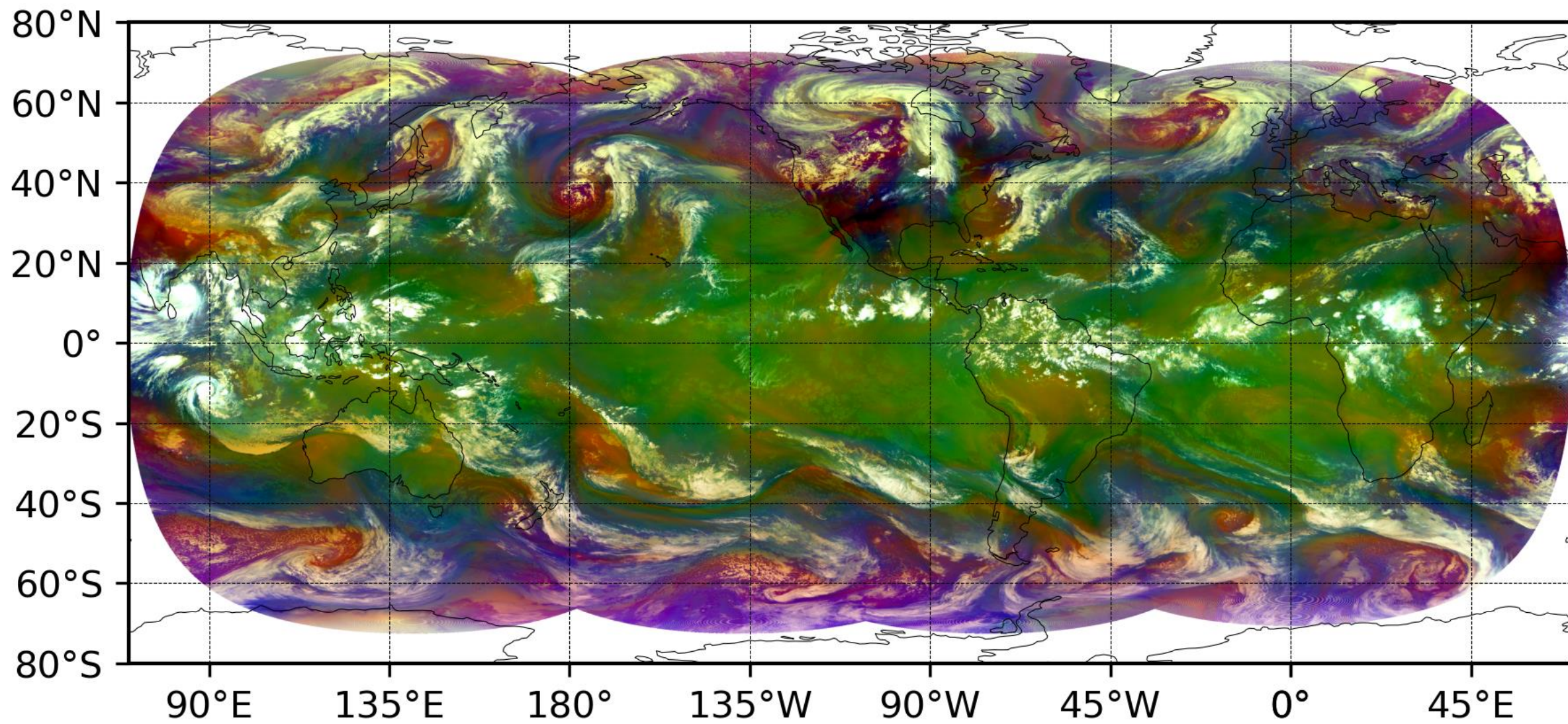
5 Aug. 2015 1600 UTC Himawari-8 AHI Night-time Microphysics RGB (a) standard EUMETSAT RGB recipe applied Red: -4 to 2 K, Green: 0 to 10 K, and Blue: 243 to 293 K and (b) recipe adjustment applied Red: -7 to 2 K, Green: -2 to 6 K, and Blue: 244 to 292 K for intercalibration.

Any difference in measured radiance and resulting brightness temperature due to either limb effects or differing spectral characteristics (e.g., spectral response function, central wavelength, or spectral bandwidth) impacts the ability to effectively analyze RGB imagery over the entire field of view and across sensors

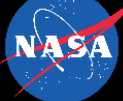




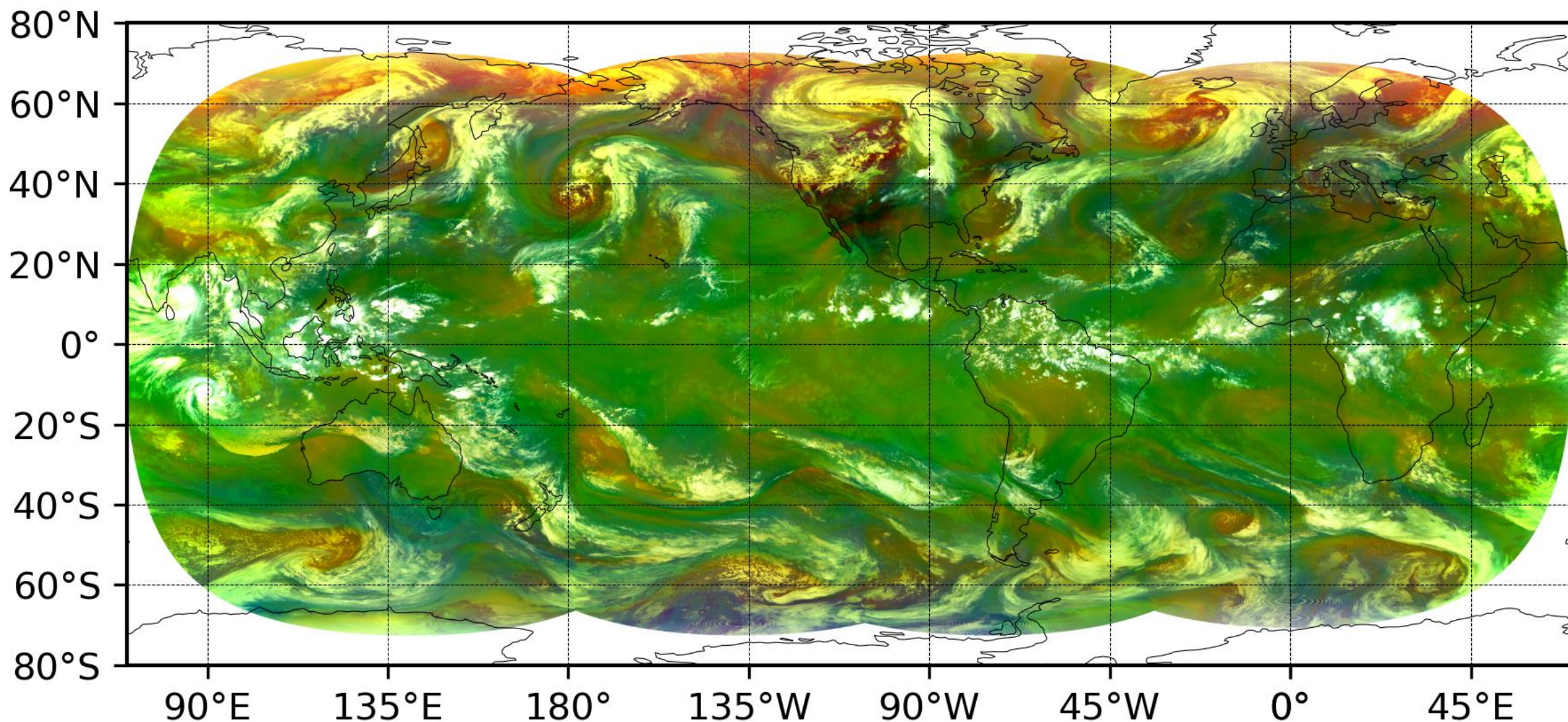
# Air Mass – No Limb Correction, No Intercalibration







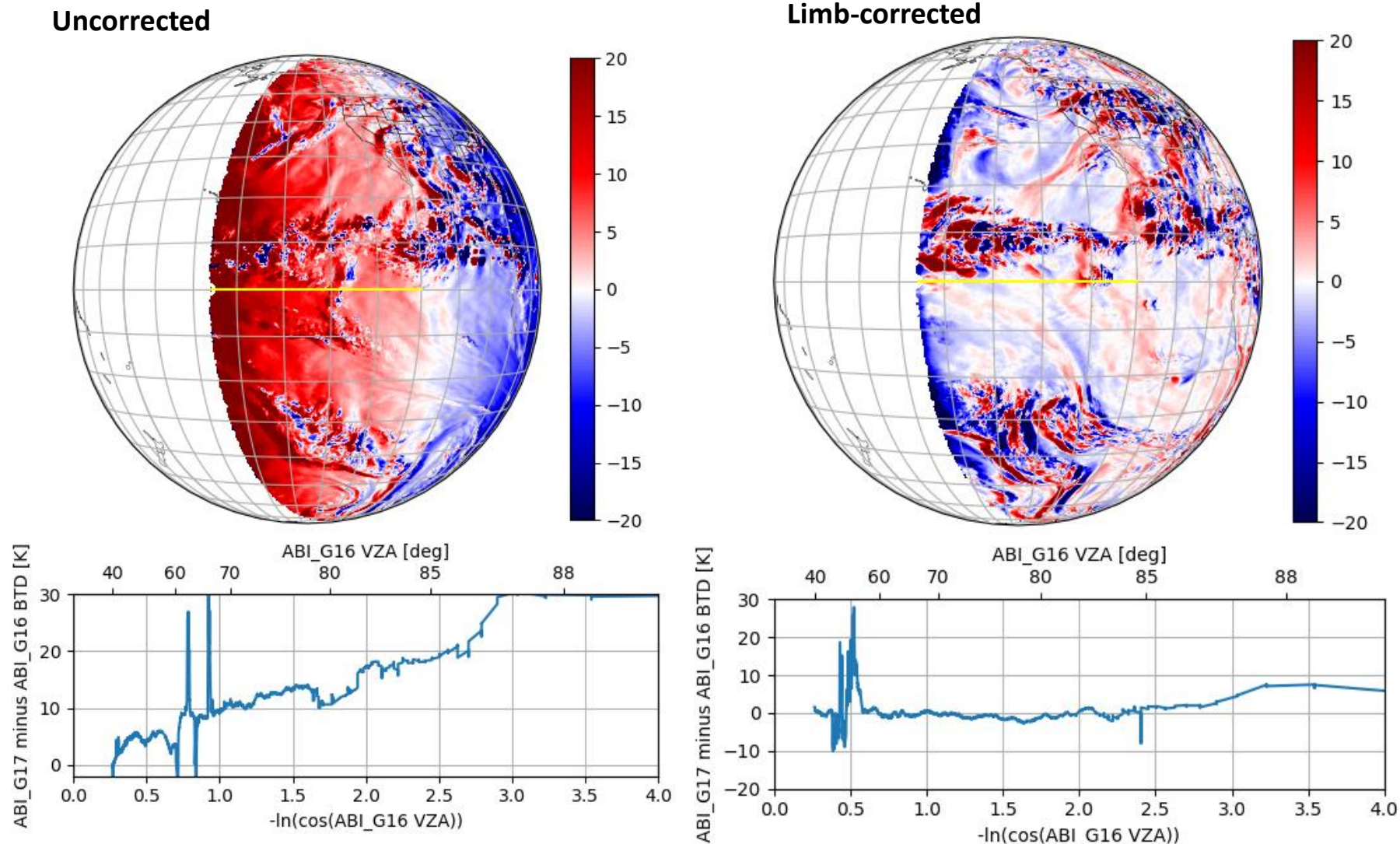
# Air Mass – Limb Correction, Intercalibration



*This work is funded by the NASA Science Mission Directorate's Earth Science Division, NASA Research Announcement NNH19ZDA001N-ESROGSS Research Opportunities in Space and Earth Science (ROSES-2019), Program Element A.33, Earth Science Research from Operational Geostationary Satellite Systems through Program Manager Dr. Tsengdar Lee*

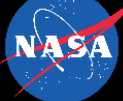


- Validation was performed through comparison of satellite imagery at collocated pixels
- Reduces the impact of limb effects from over 30K to less than 5K at  $\sim 87^\circ$  viewing zenith angle as shown in the  $7.3\ \mu\text{m}$  water vapor band
- Limb correction reduces limb effects at  $85^\circ$  viewing zenith angle by 10-20 K for all bands ( $3.9$  to  $13.3\ \mu\text{m}$ ).



*7.3  $\mu\text{m}$  water vapor band*  
GOES-17 (near-nadir) minus GOES-16 (limb) Brightness Temperature Difference  
[Yellow line corresponds with the line plot]

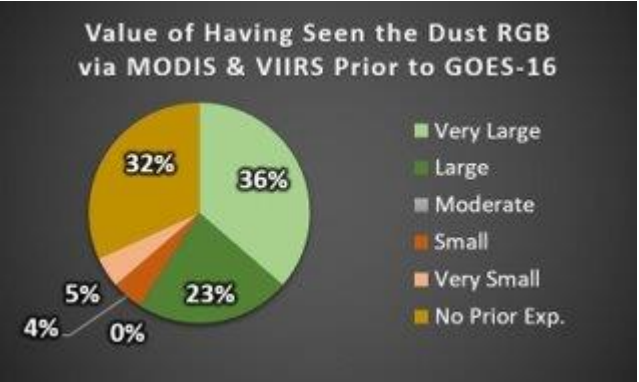




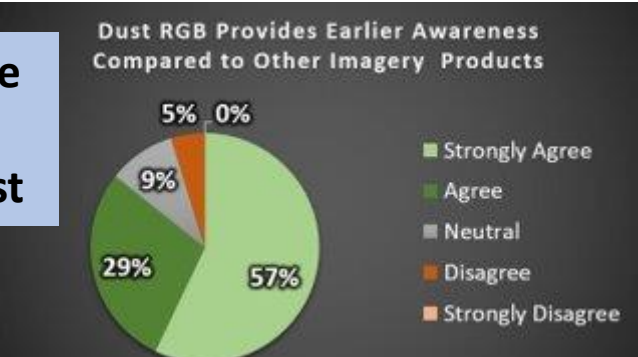
# Assessment: Dust

59% of Forecasters benefited from use of MODIS/VIIRS Dust RGB prior to GOES-16

Early proxies and training for new capabilities is important!



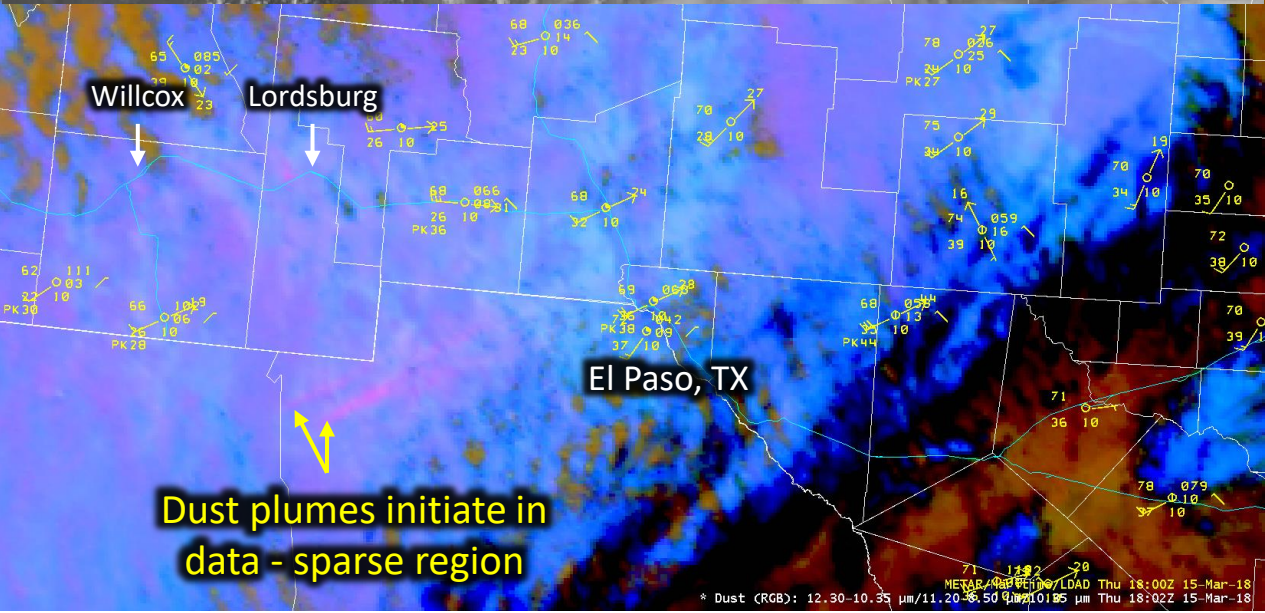
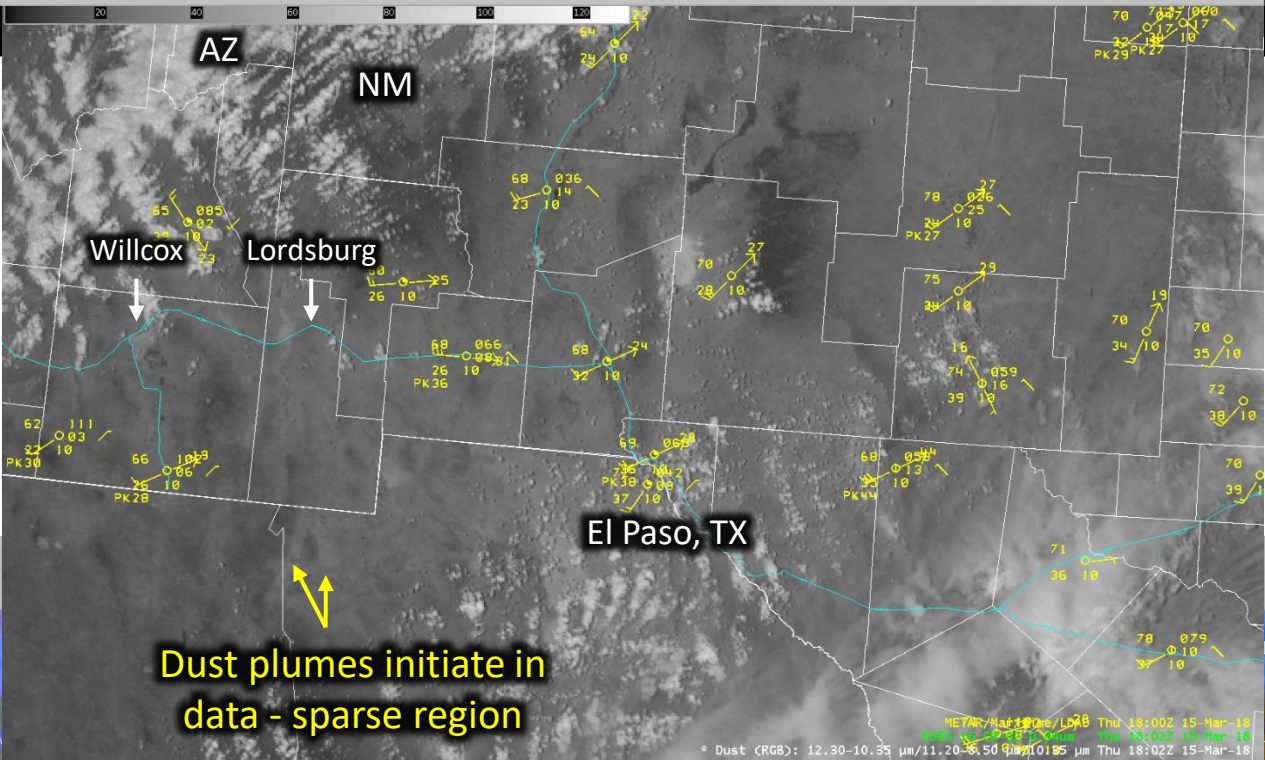
86% of Forecasters agree the Dust RGB provided earlier awareness of dust

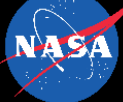


## Limitations:

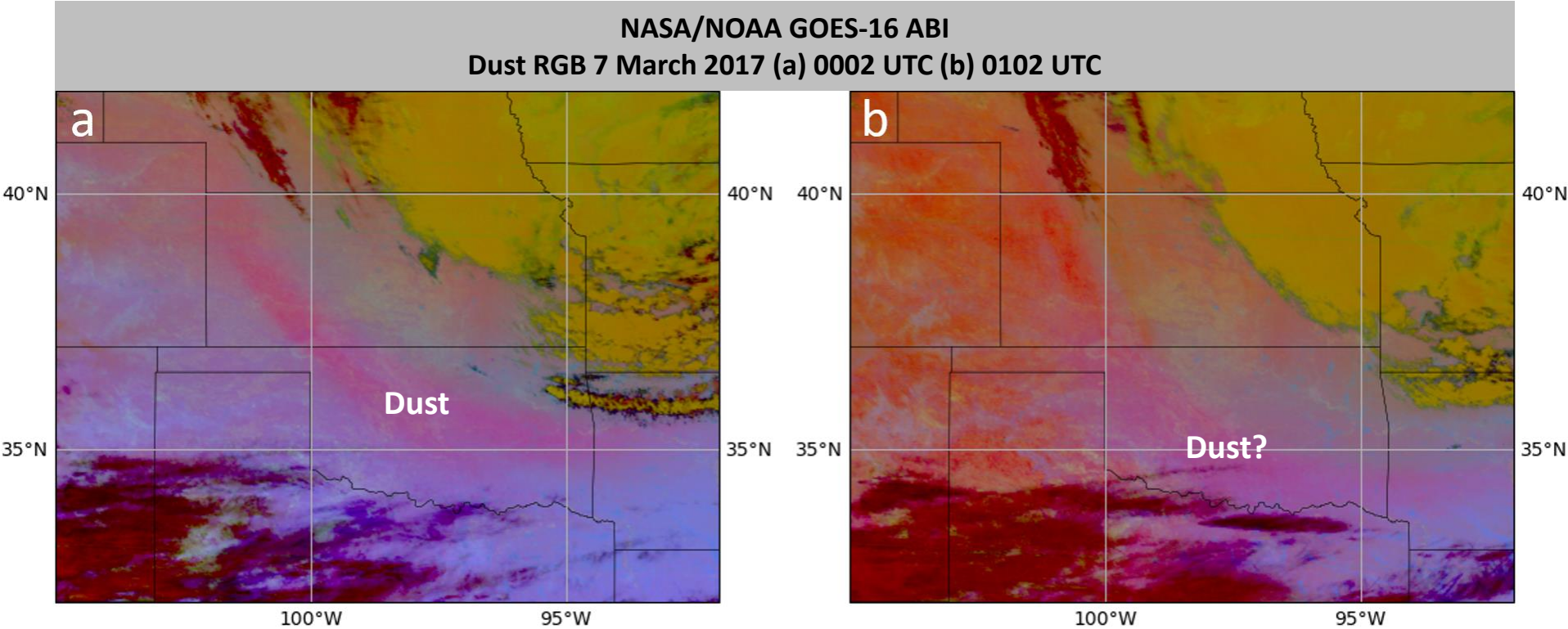
- Thin or dispersed dust
- Tracking long events into the night
- A new modified Dust RGB could address limitations

GOES-16 0.64  $\mu\text{m}$  Visible Imagery, 1802 UTC 15 March 2018





Use Perspective	AI/ML Benefits
I always lose the dust plume at night!	Identify features in difficult scenes
Which color/range of colors are dust?	A training/education tool
That looks like dust, but I'm not sure!	To improve confidence/interpretation
I can't use RGBs!	Tool to aid color vision deficiency
Is that a thin dust plume?	Quantitative aid to qualitative interpretation





- Overcoming the limitations of night-time dust detection is addressed by using expert analysis and remote sensing principles to develop training data, model inputs, and architecture.

## Focus on refining the training for Night-time dust detection

- Collect night-time training dataset
- Classify false surface and smoke detections

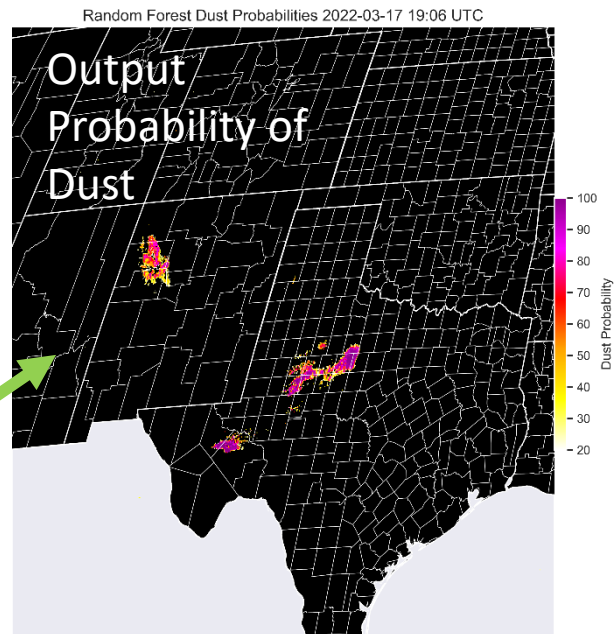
- GOES-16 ABI imagery in the SW U.S. Jan. 2018-Jun. 2020
- Cases were randomly split for Dust ML model training (60%), testing (20%), and validation (20%)
- A total of 28 cases were gathered, which incorporates 83 distinct images a total of **790,921 dust pixels** and **37,698,467 null pixels**

## Model Inputs

Single channels: 7.3, 10.35, 11.2, 12.3, 13.3  
Differences: 12.3-10.35, 11.2-8.4

Dust RGB components

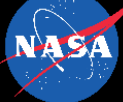
Random Forest Model



## Evaluate Training, Model Inputs, and Performance with Statistical Approaches

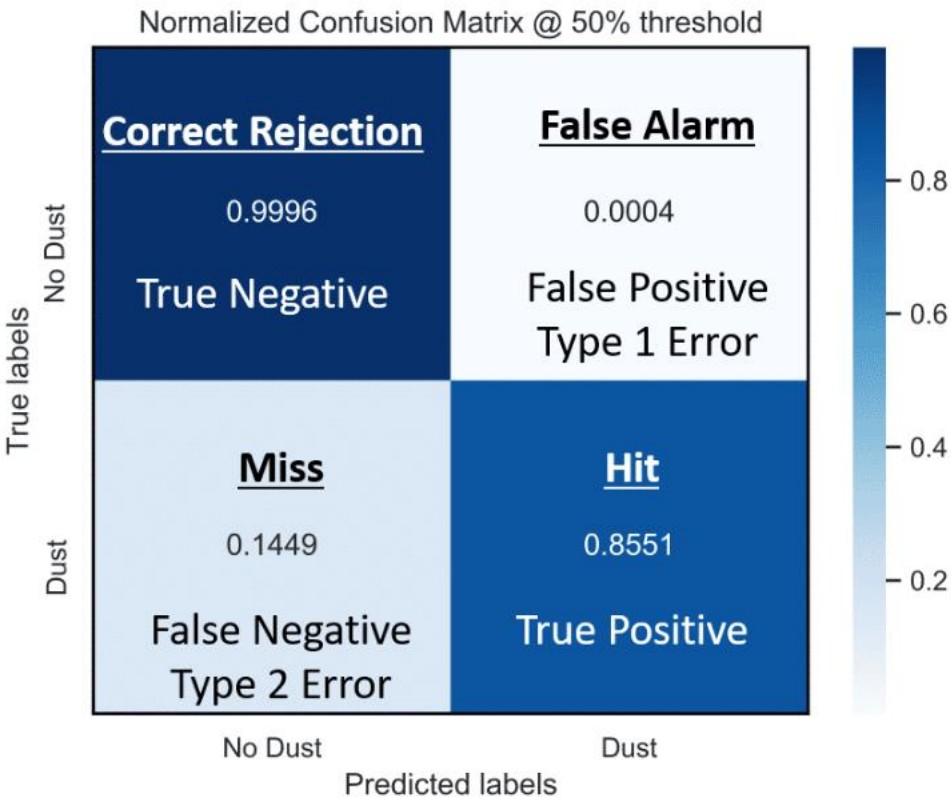
- Loss functions/Jaccard score
  - Confusion matrix
- Permutation Importance
  - ROC/AUC
  - + a few more

[More information at Berndt et al. 2021 NASA ESDS Article "Dust in the Machine"](#)



## Highly Efficient at True 'Dust' and 'No Dust' Classifications

Once a much wider set of null cases and pixels were added to the training database (similar to Fig. 8 above), the false alarm rate was reduced to less than 1% and the Dust ML model correctly identified non-dust pixels at a 99% rate. See the confusion matrix and summary cards below for the ML Dust model performance.



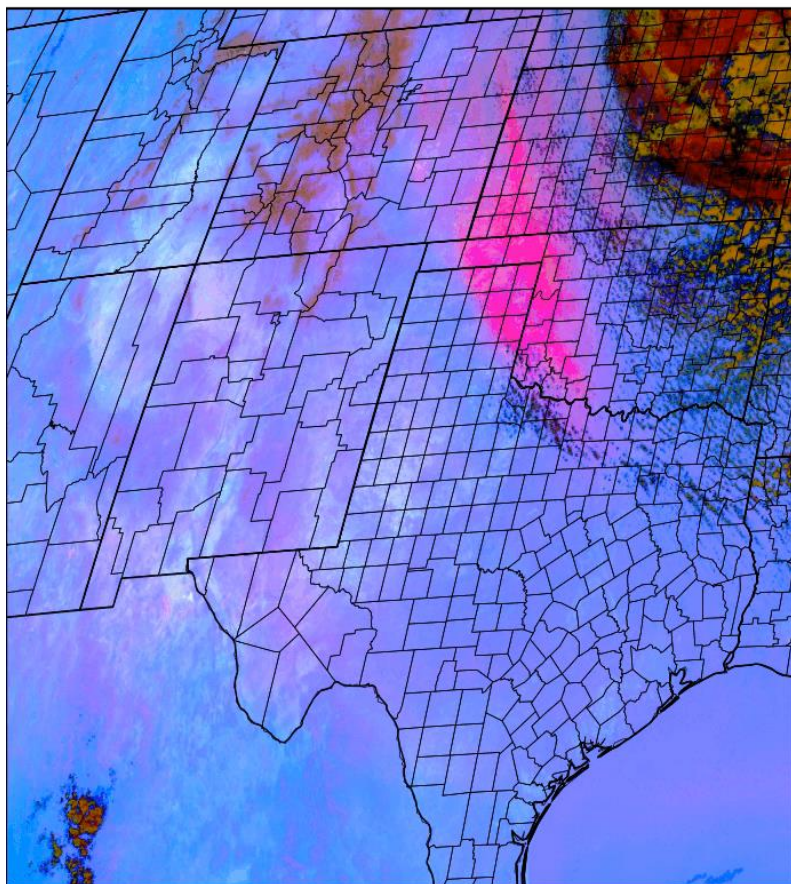
## [Finding Dust at Night](#)



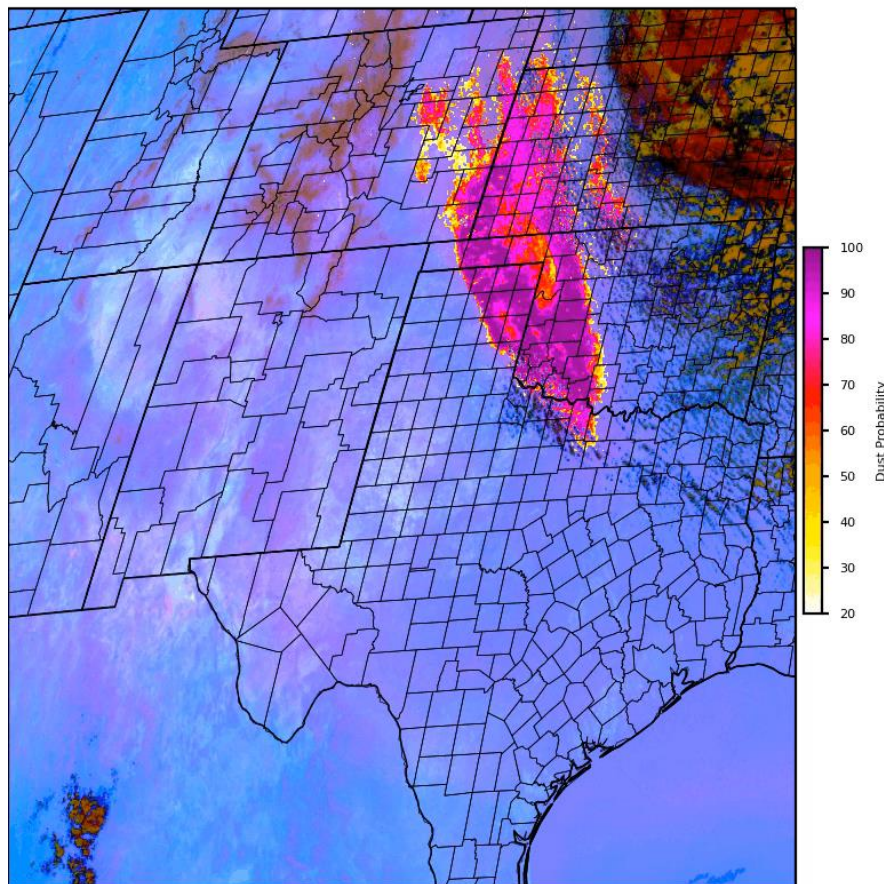


**April 7-8 Event** The Dust RGB was valued, but ML output provided a longer period of time to track dust the plume  
~Amarillo, TX WFO

GOES-16 ABI Dust RGB 2022-04-07 22:01 UTC



GOES-16 ABI Dust RGB / Dust Probabilities 2022-04-07 22:01 UTC



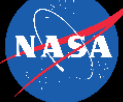
*I found the ML output very useful for tracking the plume especially in terms of overall morphology and persistence...*

*Once the solar angle got low enough and the Dust RGB started to suffer, that's when the ML model output started to shine.*

*... It certainly added additional confidence and clarity of how the dust was evolving.*

*... it gave me confidence to keep patchy dust in the forecast this evening*





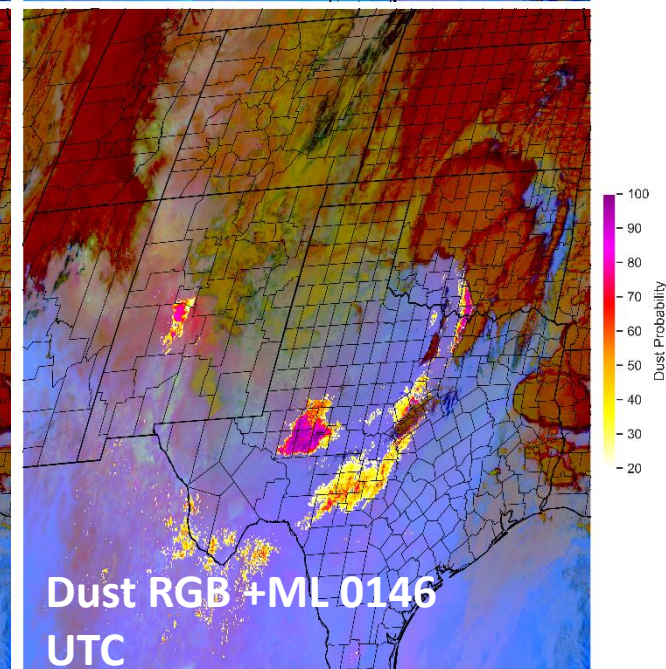
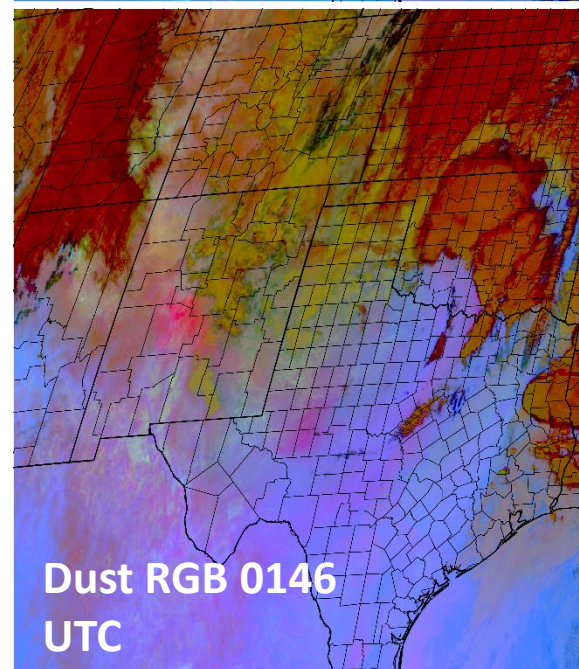
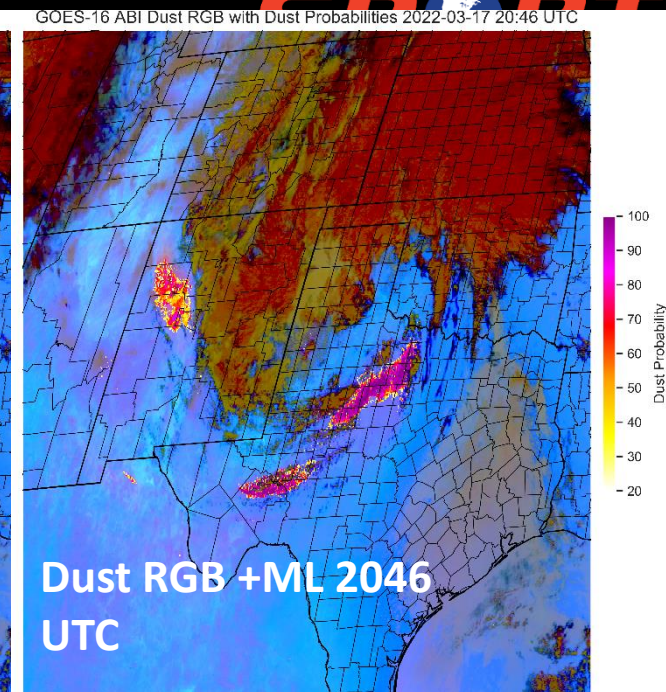
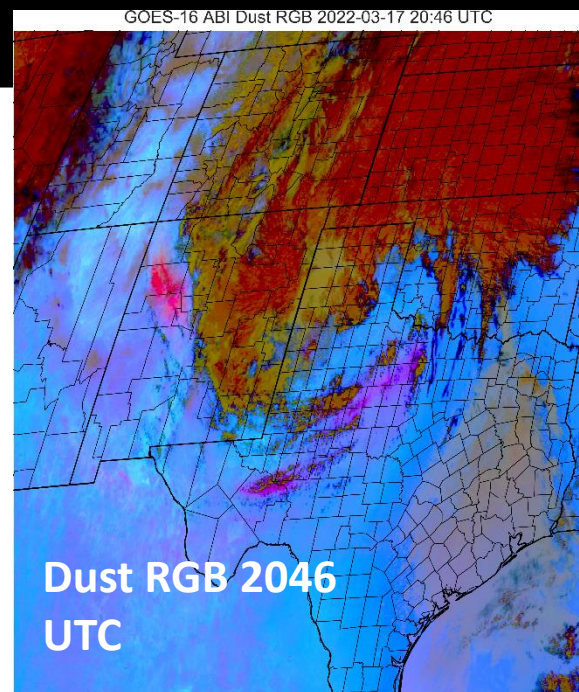
# 17 March 2022 Event

## ~Midland, TX WFO

The ML probabilities matched observations and **supplemented our decision making** when issuing a Blowing Dust Advisory,

as well as **supplemented our briefing** to Emergency Managers who were dealing with an ongoing large wildfire.

The **fact that it matched observations** early on greatly increased our confidence in the ML model output and future trends into the evening.

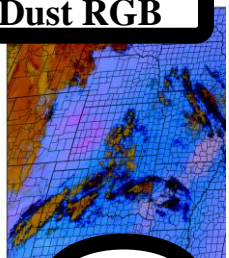




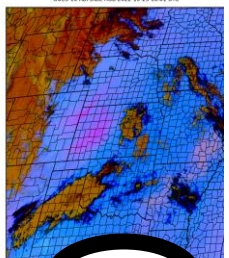
- NOW a total of 39 training Day & Night cases were gathered, which incorporates 115 distinct images a total of **1,154,064 dust pixels** and **256,932,301 null pixels**
- Assessed the incorporation of visible channels

Daytime Case

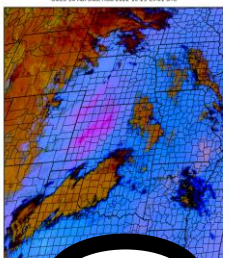
Dust RGB



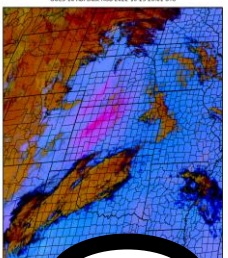
17



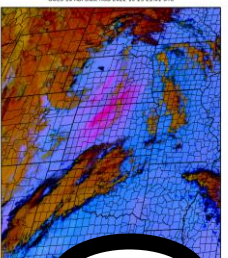
18Z



19

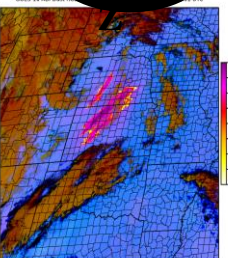
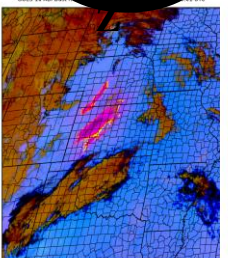
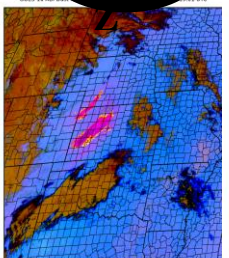
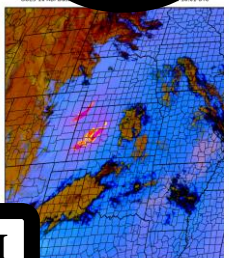
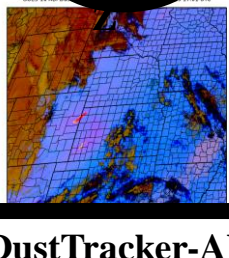


20

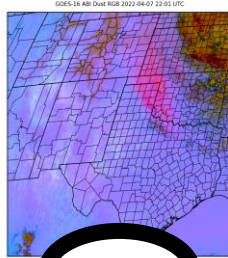


21

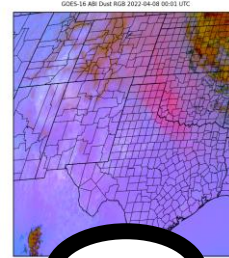
DustTracker-AI



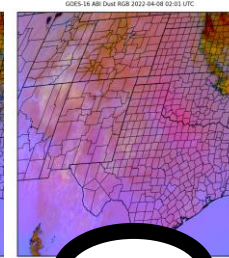
Night-time Case



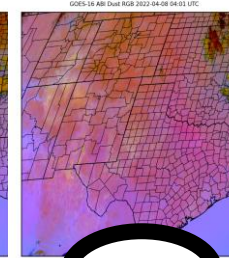
22



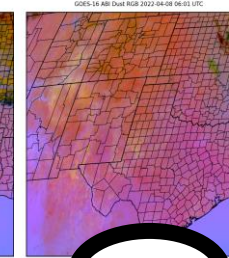
0 Z



2 Z



4 Z



6 Z

- Early SPoRT RGB research and applications include the use of NASA MODIS and VIIRS to demonstrate future GOES-R capabilities
- Key research areas to improve the use and interpretation of multispectral imagery include limb correction and intercalibration of sensors to allow for analysis across sensor field of views
- Development of ML techniques, such as the DustTracker-AI product applied to GOES-16 imagery, allows for
  - quick assessment of more than one satellite product in the moment
  - a tool that enhances the training and interpretation of imagery
  - confidence in identifying features in difficult to analyze scenes



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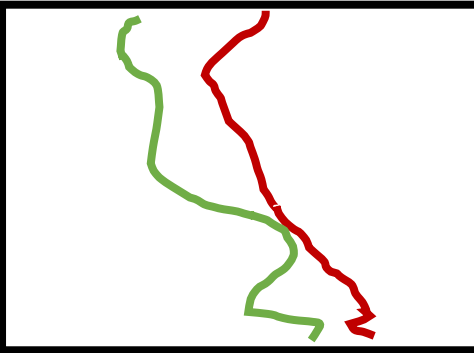
<https://weather.ndc.nasa.gov/sport/>

*Next SPoRT Stakeholder Summit & Seminar Series: March 2, 2023  
Live Demos of DustTracker-AI & GLM Stoplight Products*

# Back Up



Collected global model atmospheric profiles



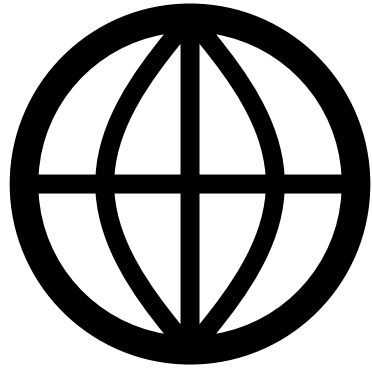
- 4-years of ECMWF ERA5 profiles
- <1 % total cloud cover threshold
- Randomly selected with even global and seasonal coverage

Modeled top of atmosphere brightness temperatures



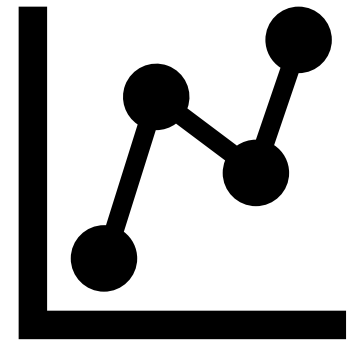
- Infrared channels for viewing zenith angles 0-80° at 5° intervals
- Simulations for each geostationary sensor

Binned brightness temperatures



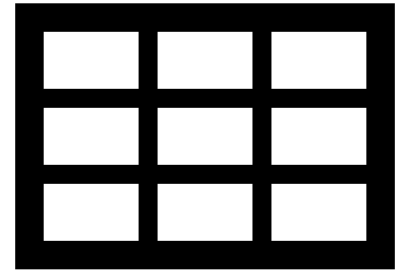
- Defined bins by 15° latitude intervals and month
- Linear best fit was determined for each bin based on the limb-correction equation

Determined statistical relationships



- Second order polynomial best fit for VZA < 60°
- First-order linear best fit for VZA > 60°
- Results in 4 best fit coefficients

Final look-up tables of limb-correction coefficients



- Coefficients fit to a continuous ninth-order polynomial surface
- The polynomial surface coefficients stored in look-up tables

For 0 – 60°:  $T_{\theta_z} - T_0 = C_2 |\ln(\cos \theta_z)|^2 + C_1 |\ln(\cos \theta_z)|$

For 60 – 80°:  $T_{\theta_z} - T_0 = C_3 |\ln(\cos \theta_z)| + C_0$

Intercalibrate a Proxy  
Reference Sensor

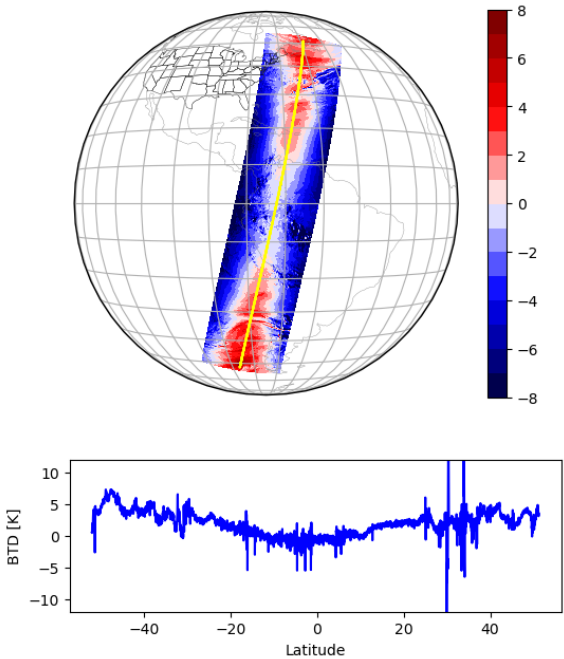
- 12 case studies of near-nadir (0-10°S), mostly clear ocean scenes
- Transect of shared points analyzed through linear regression to calculate the average monthly brightness temperature offset
- Channel-specific offset applied to Aqua MODIS

MODIS		Meteosat SEVIRI		Tb Offset
20	3.75	4	3.90	-2.96
27	6.72	5	6.25	-3.09
28	7.33	6	7.35	0.40
29	8.55	7	8.70	-0.10
30	9.73	8	9.66	-1.74
31	11.03	9	10.80	0.70
32	12.02	10	12.00	-0.41
33	13.34	11	13.40	-1.24

Compare each Geostationary Sensor  
to the Proxy Reference Sensor

- 12 case studies of cloud-cleared scenes
- Transect of shared points (40° N – 40°S) between the Proxy and geostationary sensors for single channels and band differences important to the suite of RGBs

6.2
10.3
6.2-7.3
9.7-10.8
10.3-3.9
10.3-8.6
11.2-8.6
12.4-10.3



Statistical analysis to  
determine new RGB recipes

- Scatter plots and resulting linear regression equation averaged for 12 case studies to account for seasonal variation
- Linear regression equations  $y = mx + b$  applied to original SEVIRI recipes to arrive at the proper intercalibrated-recipe
- Sensor-specific refined recipes for Air Mass, Dust, Night-time Microphysics, 24-hr Microphysics, Ash RGB, and WV RGBs

	Band or Band Difference	MSG SEVIRI Min	MSG SEVIRI Max	GOES-16 ABI Min	GOES-16 ABI Max	GOES-17 ABI Min	GOES-17 ABI Max
R	6.2-7.3	-25	0	-24.6	0.6	-24.2	-0.7
G	9.7-10.8	-40	5	-44.4	4.3	-41.6	2.0
B	6.2 (inverted)	243	208	242.4	208.7	242.8	208.9